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# EEBHub Building 101 Sankey Diagram Energy Analysis

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January 30, 2013

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**EEBHUB BUILDING 101 SANKEY DIAGRAM ENERGY ANALYSIS**

**FINAL REPORT**

**LLNL-TR-614312**

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**Lawrence Livermore National Laboratory**

**January 29, 2013**

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## Executive Summary

The Energy Efficient Buildings Hub (EEBHub) uses Sankey diagrams to visually analyze energy use in the building of its headquarters, Building 101 (B101). This report describes B101 energy consumption and passive energy exchanges with the surrounding environment and through the building. For this initial Sankey diagram exercise, completed on January 31, 2013, the data/model integration was primarily performed by calibrating the EnergyPlus model to measured energy consumption data. The annual model is used as a starting point, while iterations of the EnergyPlus simulation provide results for January and July to demonstrate how energy use changes throughout the year.

Annually, the Sankey diagram shows energy consumption from electricity and natural gas, as well as the end uses. The heating, cooling, and air handling are the largest sources of energy usage. Interior lighting and equipment are also considerable consumers of electricity.

Seasonally, the trends of energy consumption are visually demonstrated by comparing January and June Sankey diagrams. As expected, winter requires heating via the boiler as the largest energy consumer, while much of the building heat is lost to the exterior. The summer months have several sources of heat, both exterior and interior, to the building. Cooling is the largest consumer of electricity in July, followed by interior lighting and equipment, and the air handling. From these seasonal diagrams, it is easy to recognize the building's interactions with its environment, and the strain that induces on its energy consumption. These visualizations help identify where equipment modifications (with better efficiencies) can reduce energy consumption.

This report demonstrates the integration of multiple sources of data to output a “broad” picture of engineered and environmental fluxes of energy through the EEBHub. The outcomes of this project are to provide a building energy analysis on B101 that helps identify large sources of energy consumption, gaps in data, and provide opportunities to deploy energy saving technologies. Future work may include re-rendering this energy flow diagram as a part of a “live” building energy display based on real-time metered energy data and a reduced-order model of environmental fluxes of energy.

## Introduction

The Energy Efficient Buildings Hub (EEBHub) requested visualization of building energy flows in Sankey format. These diagrams provide a compact representation of quantitative information from multiple sources of data. This work will lay the groundwork for visualizing building energy use within the Greater Philadelphia Region, which is crucial to demonstrating the success of EEBHub.

The Sankey diagrams address several objectives identified by EEBHub

- Integrate design, construction, commissioning, and operation of buildings
- Integrate energy saving technologies for whole building system solutions at the Navy Yard and elsewhere in the region
- Inform, train, and educate people (i.e. policy makers, community, workforce) about proven energy saving strategies and technologies

The outcomes of this project are to

- Use the diagrams as a template for retrofits
- Identify gaps in data
- Recognize large sources of energy consumption
- Provide opportunities to deploy energy saving technologies.

This report describes the energy usage and flows through Building 101 (B101). The starting point of this project was a qualitative Sankey diagram based on hypothetical flows of energy through the building. These flows included passive energy fluxes (transfers of energy through the building envelope to and from the surrounding environment) and active use of energy in typical systems such as HVAC and lighting.

Building 101 is highly instrumented with respect to its active energy systems, and both electrical and natural gas energy consumption can be measured quite accurately for many of the buildings subsystems. However, the passive energy fluxes cannot be measured directly. Some instrumentation that measures the indicators required to calculate those fluxes has been installed (inside/outside temperatures, incident radiation, wind speed, etc.). But the instrumentation is not extensive enough to fully render the energy exchange between the inside and outside of the building.

Therefore, generating data for the B101 Sankey diagrams requires an integration of modeling outputs, sensor data, and references of building energy exchange, including:

- 1) Electricity and natural gas utility data
- 2) Energy Plus simulation output (version 1009), provided by Ke Xi
  - a. Using sensor data as calibration
- 3) Building and monitored live data (provided by Scott Wagner)
  - a. mainly in EEBHub, located in north end of the 2<sup>nd</sup> floor of B101

The quantitative Sankey flows changed as our understanding of B101 evolved. New information and data from modelers and collaborators allowed for an iterative refinement of the Sankey diagram. Modifications to the initial EnergyPlus model provided detailed data to include two

monthly Sankey diagrams; one in July to depict summer energy flow, and one in January to show winter energy flows.

Every effort was made to consolidate all of the analysis required to fully render the B101 Sankey diagram into the Energy Plus model. Where further analysis was required, we chose to use simple approximations (detailed in Appendix B), rather than physics-based models. While these approximations may introduce some inaccuracy in the values reported on the Sankey diagram, they are designed to be replaced by updates to the Energy Plus model, and are not “buried” in additional models and spreadsheets. Work is ongoing to generate reports from EnergyPlus with the additional information required to replace these assumptions.

## EEBHub Building 101 Sankey Diagrams

Sankey diagrams depict energy usage and exchange between building components. Some details were not specifically defined in the output, and are listed below as estimated parameters and calculated flows.

### EnergyPlus output:

EnergyPlus simulation results define many of the Sankey energy flows. Annual and monthly simulation output gives energy breakdowns of the components that consume natural gas and electricity. The simulation also outputs heat gains contributions to the thermal envelope, including contributions from exterior surfaces, windows, infiltration, HVAC, lights, equipment, and people. Tables from the EnergyPlus output used to develop the Sankey diagrams are in Appendix A.

### Estimated parameters:

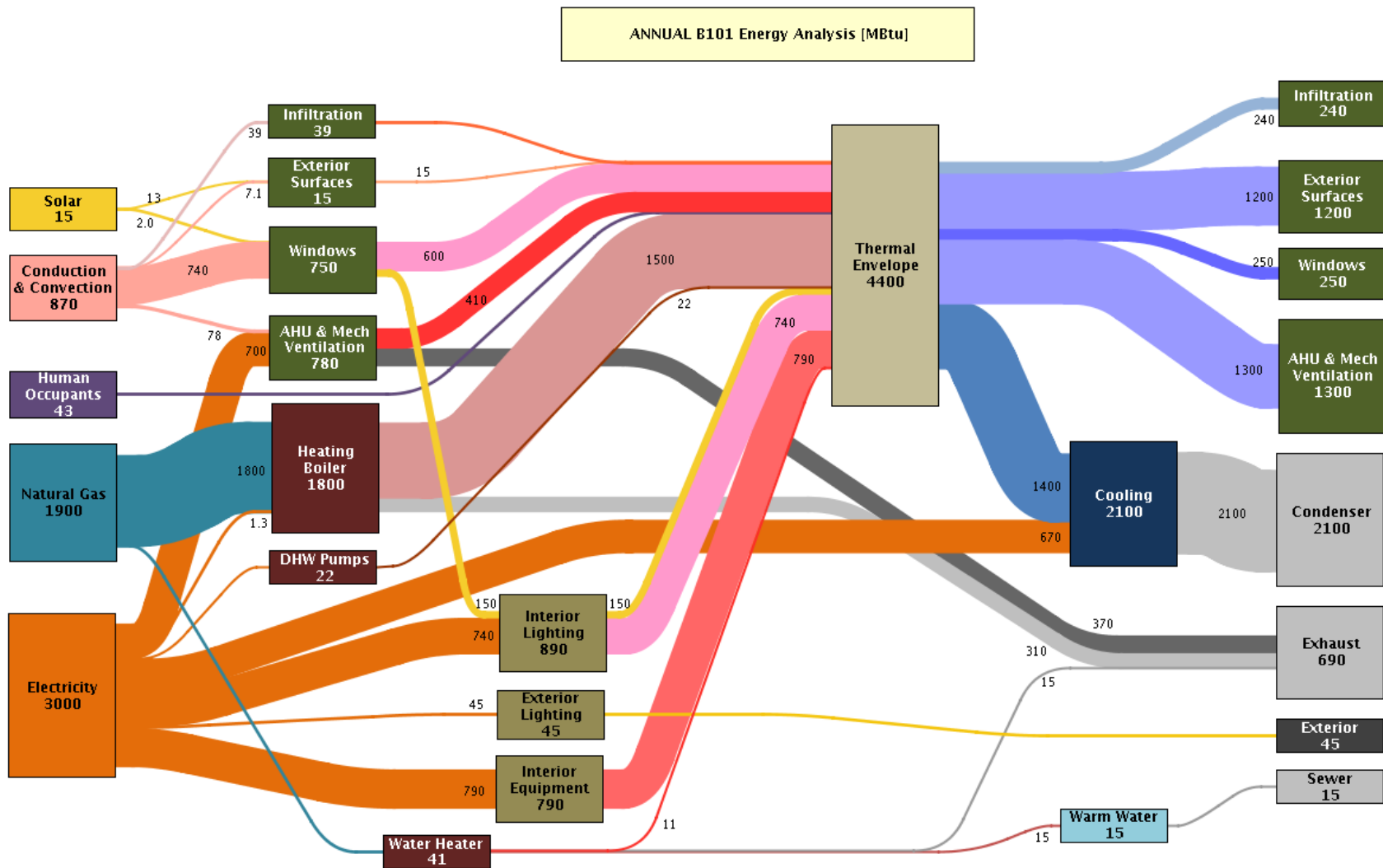
When specific component data was not available, assumptions were made to estimate energy flows. Detailed information for the following energy flows are described in Appendix B.

- Solar → exterior surfaces
- Solar → windows
- Convection & conduction → infiltration
- Convection & conduction → AHU & mechanical ventilation
- Windows → interior lighting
- AHU & mechanical ventilation → exhaust
- AHU & mechanical ventilation → thermal envelope
- Water heater → thermal envelope
- Water heater → exhaust

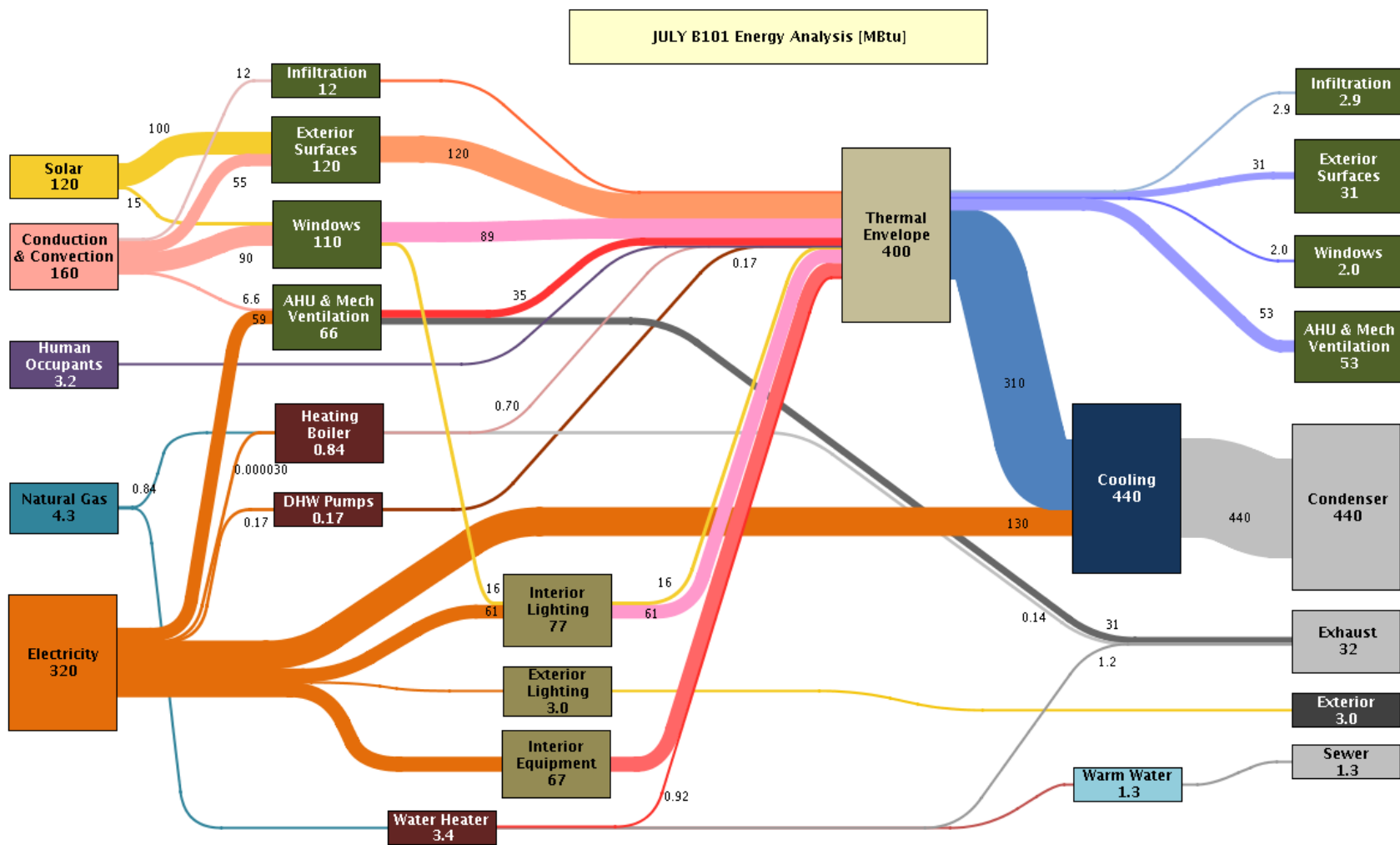
### Calculated flows from energy balance:

Over each of the time periods analyzed (full year, winter month, summer month), the energy inflows and outflows balance at each component (Sankey box), allowing us to calculate parameters that are not specified or difficult to quantify. These include the following:

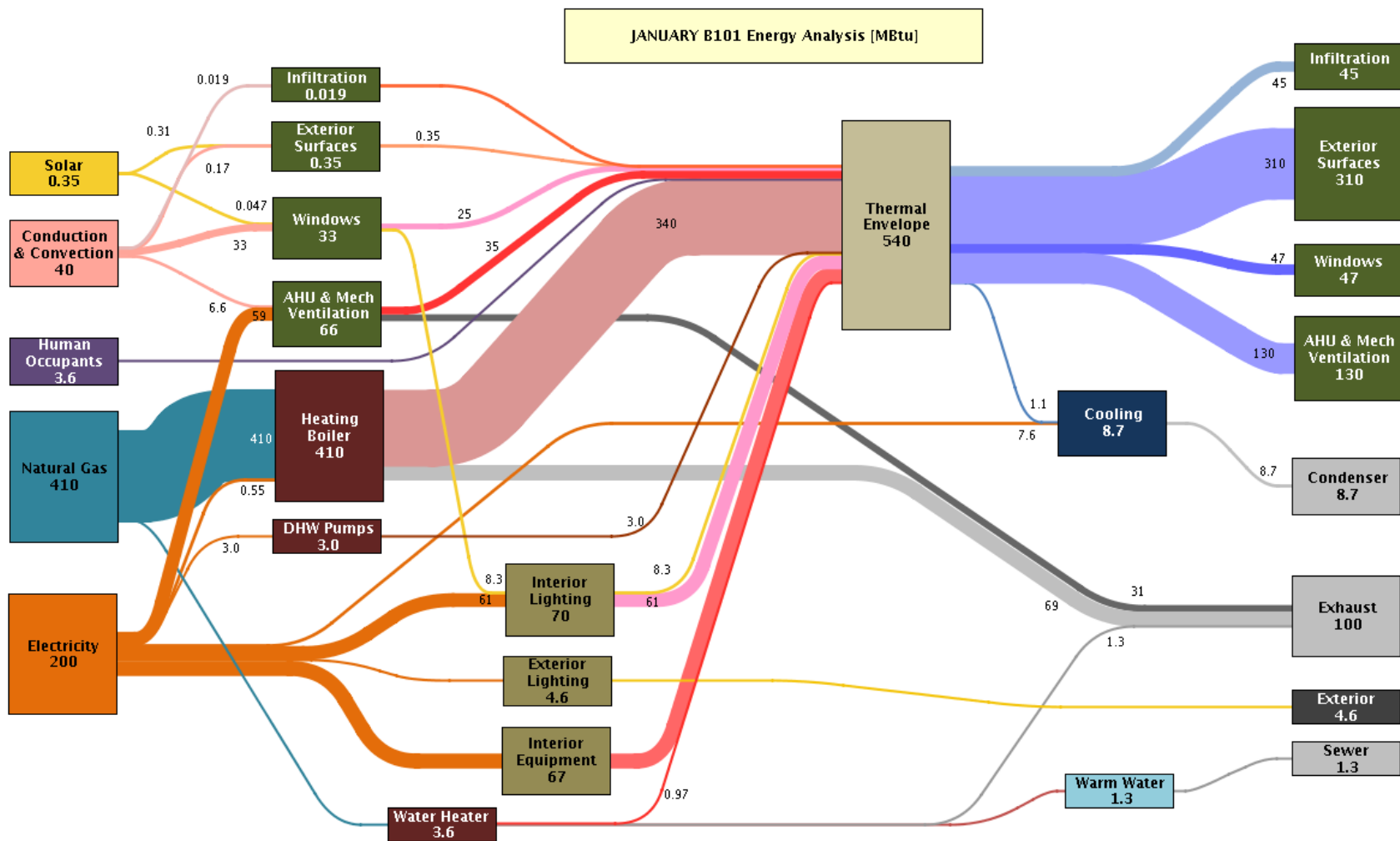
- Convection & conduction → windows
- Heating boiler → exhaust
- Interior lighting → thermal envelope
- Thermal envelope → AHU & mechanical ventilation
- Air conditioning → condenser



**Figure 1** B101 Annual Sankey Diagram. Details for the flow values are in Appendix A and B



**Figure 2** B101 July 2011 Sankey Diagram. Details for the flow values are in Appendix A and B



**Figure 3** B101 January 2012 Sankey Diagram. Details for the flow values are in Appendix A and B

## Conclusions

Rendering the energy flow through B101 as a Sankey diagram has been a useful exercise for the EEBHub team. Nowhere else in the voluminous quantity of data and model outputs have the engineered and environmental fluxes of energy through the Hub space been consolidated into a single visual reference.

The full-year diagram contains the most important energy statistics for the building: annual electricity and natural gas consumption, as well as energy consumption for most of the building's critical functions (heating, air conditioning, lighting, hot water, etc.). However, this diagram does not assist the Hub in evaluating the building's performance. Because it is an annual diagram, it "appears" that heating energy is offset by cooling effort, whereas in reality, these two energy transfers happen asynchronously.

From the full-year diagram, it is clear that heating, air handling, lighting and air conditioning are the building's largest uses of energy, with interior equipment (office equipment and other miscellaneous plug load) also contributing heavily. While some other systems may not be optimally performing, it is clear where upgrades or retrofits could make the largest difference.

The two seasonal diagrams (January, June) give the reader a much better view into B101's energy performance. In winter, much of the thermal load is lost to the exterior through heat losses to the walls, windows and infiltration. The largest source of energy consumption is natural gas that provides a large amount of heating to the building. In summer, the boilers are turned off as is reflected in the Sankey diagram. Heating to the building is reflected in contributions from several sources: the exterior environment (i.e. solar) providing heat, and interior components give off heat (lights, equipment). The largest energy loss from the building is due to the cooling.

From these seasonal diagrams, it is easy to recognize the building's interactions with its environment, and the strain that induces on its energy consumption. It is also evident that in the summer months, non-environmental heat gain (equipment, lighting, etc.) is a significant, but not dominating contributor to the air conditioning load. More efficient equipment would have the double-bonus of both reducing energy consumption directly as well as diminishing cooling energy consumption.

Future work may include re-rendering this energy flow diagram as a part of a "live" building energy display based on real-time metered energy data and a reduced-order model of environmental fluxes of energy.

## References

### ENERGYPLUS™ Documents

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EnergyPlus Engineering Reference: The Reference to EnergyPlus Calculations  
May 24, 2012

Input Output Reference: The Encyclopedic Reference to EnergyPlus Input and Output  
Date: May 24, 2012

Output Details and Examples: EnergyPlus Outputs, Example Inputs and Data Set Files  
Date: October 2, 2012

2009 ASHRAE HANDBOOK – FUNDAMENTALS (SI Edition). American Society of Heating, Refrigerating and Air-conditioning Engineers

Phone conversation. Ke Xi, Scott Wagner

Emails. Ke Xi, Scott Wagner

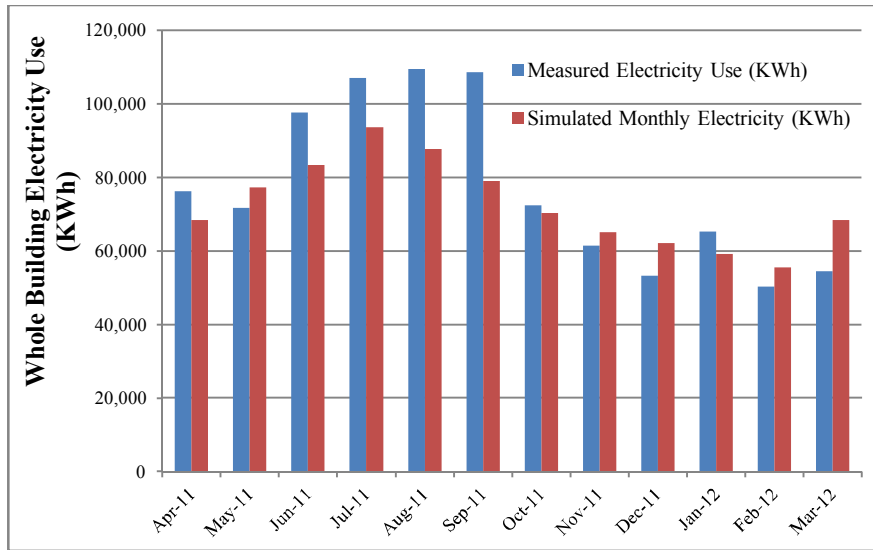
## Appendix A: Energy Component Data for Sankey Diagrams

The total natural gas and electricity simulated data is used as a starting point to generate the Sankey diagram. Most of the natural gas flow goes toward heating through the boiler with some residual to parasitic losses. The electricity use is spread across heating, cooling, lighting, interior equipment, and other HVAC components.

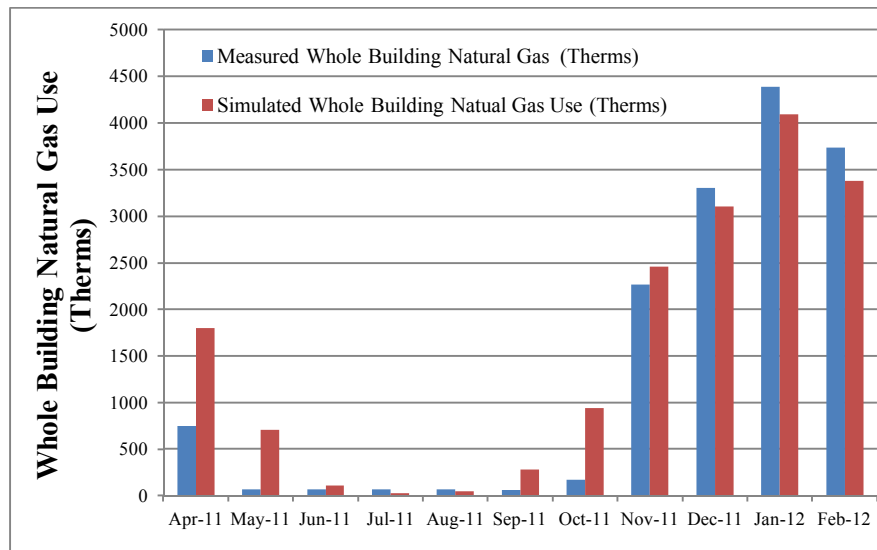
**Table A1** EnergyPlus simulated end use values for electricity and natural gas annually, for January, and July [MBtu].

	Annual Electricity [MBtu]	Annual Natural Gas [MBtu]	January Electricity [MBtu]	January Natural Gas [MBtu]	July Electricity [MBtu]	July Natural Gas [MBtu]
Heating	1.34	1843.50	0.55	407.33	0.00	0.84
Cooling	674.63	0.00	7.59	0.00	127.21	0.00
Interior Lighting	737.95	0.00	61.34	0.00	61.34	0.00
Exterior Lighting	44.66	0.00	4.59	0.00	3.01	0.00
Interior Equipment	793.95	0.00	66.72	0.00	66.72	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	698.11	0.00	59.01	0.00	59.37	0.00
Pumps	22.50	0.00	3.02	0.00	0.17	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	41.42	0.00	3.60	0.00	3.41
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total End Uses</b>	<b>2973.13</b>	<b>1884.92</b>	<b>202.82</b>	<b>410.93</b>	<b>317.81</b>	<b>4.25</b>

Most of the higher level energy usage values depicted in the Sankey diagram are taken from EnergyPlus model results dating from April 2011 to March 2012. For comparison, the measured vs. simulated building electricity and natural gas usage are shown in figure A1 and figure A2 below.



**Figure A1** Simulated and Measured Monthly Electricity use for B101



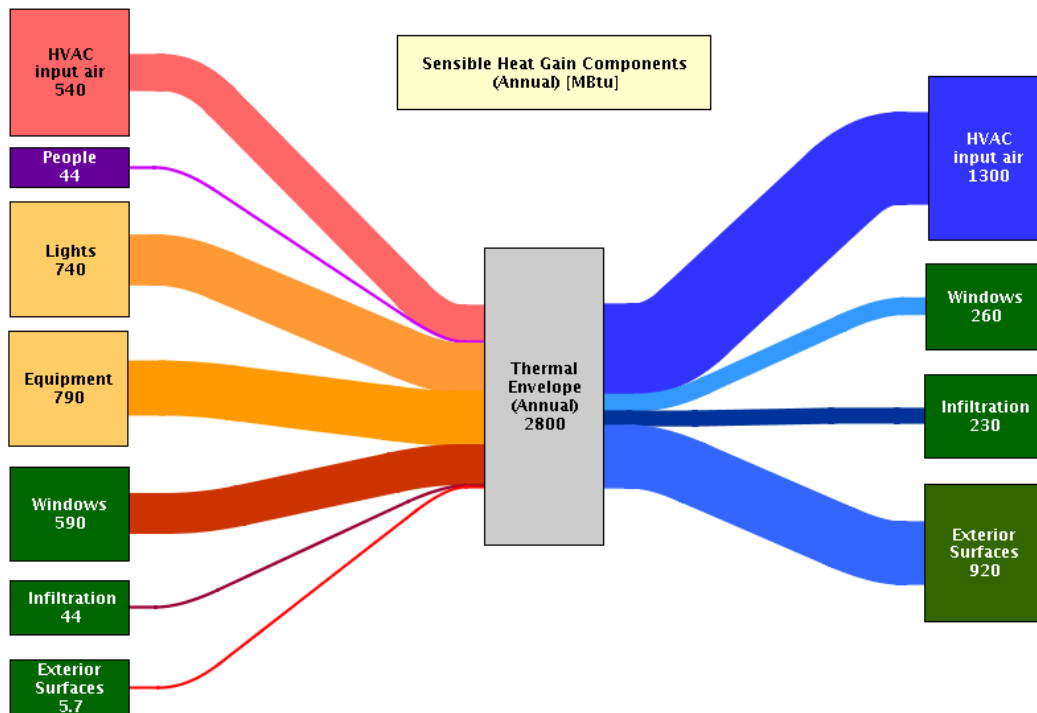
**Figure A2** Simulated and Measured Monthly Natural Gas use for B101

### Sensible Heat Gains:

**Table A2** B101Total Facility Annual Sensible Heat Gain Components based on 58 zones throughout the building annually, for January, and for July [MBtu] (from Output Report: Sensible Heat Gain Summary)

Sensible Heat Gain Components [MBtu]	Annual	January	July
HVAC Input Sensible Air Heating	825.82	250.53	0.10
People Sensible Heat Addition	43.05	3.57	3.15
Lights Sensible Heat Addition	737.95	61.34	61.34

Equipment Sensible Heat Addition	793.95	66.72	66.72
Window Heat Addition	597.04	25.05	89.24
Infiltration Heat Addition	38.78	0.02	12.10
Opaque Surface Conduction and Other Heat Addition	15.13	0.35	116.27
HVAC Input Sensible Air Cooling	-1384.29	-1.12	-312.41
Window Heat Removal	-248.32	-46.90	-2.04
Infiltration Heat Removal	-236.33	-44.69	-2.93
Opaque Surface Conduction and Other Heat Removal	-1181.83	-314.86	-31.34



**Figure A3** Sankey visual of EnergyPlus Simulated Annual Sensible Heat Gain Components (October 2012 file, not updated). Energy balance seems to assume HVAC input heated and cooled surface, interzone air transfer, and equipment heat removal are zero:  $(HVAC\ Input\ Air\ Heating) + Heat\ Addition\ (People + Lights + Equipment + Window + Infiltration) + (Opaque\ Surface\ Conduction\ and\ Other\ Heat\ Addition) = 12 * (HVAC\ Input\ Air\ Cooling) + Heat\ Removal\ (Window + Infiltration) + (Opaque\ Surface\ Conduction\ and\ Other\ Heat\ Removal)^1$ .

<sup>1</sup> note: the coefficient "12" converts ton-hrs to kBtu

The tables below are taken from the Annual EnergyPlus Output Report and email correspondence with EEBHub collaborators. Not all tables were put in this report due to space. Only the data that was considered in our analysis is included. More information on what sub-reports are contained in the Output Report are shown in Appendix D.

Boiler:

**Table A3** EnergyPlus boiler characteristics (from Output Report: Component Sizing Summary)

	Type	Nominal Capacity [Btu/h]	Nominal Efficiency [Btu/Btu]
BOILER	Boiler:HotWater	2049914.89	1

Cooling Coils:

**Table A4** EnergyPlus cooling coil characteristics (from Output Report: Equipment Summary)

	Type	Nominal Total Capacity [Btu/h]	Nominal Sensible Capacity [Btu/h]	Nominal Latent Capacity [Btu/h]	Nominal Sensible Heat Ratio	Nominal Efficiency [Btu/Btu]
2NDFLOOR:NTELECONFROOM PTHP DX COOLING COIL	Single Speed	13130.1	10486.43	2643.68	0.8	3
AHU1 AHU UNITARY DX COOLING COIL	Single Speed	435981.9	299042.38	136939.52	0.69	2.94
AHU2 AHU UNITARY DX COOLING COIL	2-Stage Humidity Control	715970.28	518307.3	197662.97	0.72	3.1
AHU3 AHU UNITARY DX COOLING COIL	2-Stage Humidity Control	715970.28	518307.3	197662.97	0.72	3.1

DX Cooling Coils:

**Table A5** EnergyPlus cooling coil characteristics (from Output Report: Equipment Summary)

	DX Cooling Coil Type	Standard Rating (Net) Cooling Capacity [ton]	SEER in SI Units [Btu/Btu]	EER in SI Units [Btu/Btu]	IEER in SI Units [Btu/Btu]
2NDFLOOR:NTELEC ONFROOM PTHP DX COOLING COIL	Single Speed	1	2.66	2.51	2.55
AHU1 AHU UNITARY DX COOLING COIL	Single Speed	36	3.01	2.83	3.13

Fans:

**Table A6** EnergyPlus fan characteristics (from Output Report: Equipment Summary)

	Type	Total Efficiency [Btu/Btu]	Delta Pressure [psi]	Max Air Flow Rate [ft3/min]	Rated Electric Power [W]	Rated Power Per Max Air Flow Rate [W-min/ft3]	Motor Heat In Air Fraction
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2NDFLOOR: NTeleConfRm PTHP SUPPLY FAN	OnOff	0.7	0.09	492.52	199.26	0.4	1
AHU1 AHU SUPPLY FAN	Variable Volume	0.67	0.16	11338.74	8944.76	0.79	1
AHU2 AHU SUPPLY FAN	Variable Volume	0.69	0.18	21397.61	17774.7	0.83	1
AHU3 AHU SUPPLY FAN	Variable Volume	0.69	0.16	20497.72	15108.16	0.74	1

#### Pumps:

**Table A7** EnergyPlus cooling pump characteristics (from Output Report: Equipment Summary)

	Type	Control	Head [psi]	Water Flow [gal/min]	Electric Power [W]	Power Per Water Flow Rate [W-min/gal]	Motor Efficiency [Btuh/Btuh]
DHW LOOP SUPPLY PUMP	Constant Speed	Continuous	9.1	1.9974	62.3	31.19	0.9
HW LOOP SUPPLY PUMP	Constant Speed	Intermittent	17.34	69.0038	1125	16.3	0.9

#### Water Heater:

**Table A8** EnergyPlus water heater characteristics (from Output Report: Equipment Summary)

	Type	Storage Volume [ft3]	Input [Btu/h]	Thermal Efficiency [Btuh/Btuh]	Recovery Efficiency [Btuh/Btuh]	Energy Factor
WATER HEATER 1	Mixed	13.39	198991.74	0.82	0.64	0.37
WATER HEATER 2	Mixed	13.39	198991.74	0.82	0.64	0.37

#### Ventilation:

**Table A9** Exhaust fan flow and Fresh air intake data for B101, October 2012 (email from S. Wagner "Fresh Air - Exhaust Air Balance Data Bldg 101 for LLNL - Oct '12.xlsx")

October 2012	Monthly Total
Total Exhaust Fan Flow [cf]:	72,110,869
Total Fresh Air Intake [cf]:	152,875,837
exhaust fan flow/fresh air intake	47.2%

#### Exterior Fenestration:

**Table A10** Average or Total values based on 176 simulated zones (from Output Report: Envelope Summary)

Average glass SHGC	0.703
Total Glass Area (ft <sup>2</sup> )	2110

Estimated Annual Incident Irradiance (MBtu)	0.26
annual estimated heat loss based on SHGC	386

Building Envelope: Windows and walls:

**Table A11** (from Output Report: Input Verification and Results Summary)

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [ft2]	48927.14	8042.34	16435.79	7982.47	16466.53
Window Opening Area [ft2]	7407.06	1066.94	2265.57	1170.59	2903.96
Window-Wall Ratio [%]	15.14	13.27	13.78	14.66	17.64

Climate:

**Table A12** Solar radiation characteristics for Philadelphia, PA

[[<http://solarelectricityhandbook.com/solar-irradiance.html>. “solar irradiance on a vertical surface in Philadelphia”]

	Average incident solar radiation (MBtu)			Average transmitted solar radiation (MBtu) for double glazing		
	Jan	July	Year	Jan	July	Year
North unshaded	1.53	4.67	36.24	1.05	3.06	24.49
East unshaded	8.85	21.70	189.69	6.11	15.38	133.29
South unshaded	9.46	7.76	110.48	7.09	4.73	75.95
West unshaded	10.63	25.47	222.60	7.42	18.05	156.42
<b>Total</b>	<b>30.47</b>	<b>59.59</b>	<b>559.00</b>	<b>21.67</b>	<b>41.22</b>	<b>390.15</b>

## Appendix B: Assumptions for B101 Sankey Diagrams

### Estimated parameters:

When specific energy breakdowns were not available, some assumptions were made to estimate energy flows. These include the following:

- Solar → exterior surfaces
- Solar → windows
- Convection & conduction → infiltration
- Convection & conduction → AHU & mechanical ventilation
- Windows → interior lighting
- AHU & mechanical ventilation → exhaust
- AHU & mechanical ventilation → thermal envelope
- Water heater → thermal envelope
- Water heater → exhaust

The estimated annual irradiance used for calculations in Philadelphia, PA is  $\sim 76 \text{ kWh/ft}^2$  ( $0.26 \text{ MBtu/ft}^2$ ). [<http://solarelectricityhandbook.com/solar-irradiance.html>]

### Solar:

The fraction of solar reaching the windows and solar reaching the building exterior and is assumed to be proportional to the window-to-wall ratio (Table A11). Although there is some solar tracking and metered data on some B101 surfaces, none of that data was used in our analysis (other than what is embedded in the EnergyPlus model). The opaque surface conduction was used to estimate the solar flow to the exterior surfaces and windows.

### Convection & conduction:

Convection was not a source of external heat transfer in the EnergyPlus output, and was not explicitly extracted. It was still included in the Sankey diagram with the understanding that there is some contribution of heat transfer as convection through the windows and exterior surfaces to the building envelope.

As mentioned in the introduction, efforts to limit physics based analysis required other assumptions to be made. Thus, rough approximations were used to estimate the heat gain “split” between solar and convection/conduction to the exterior surfaces and windows. The ASHRAE fundamentals handbook gives a table of recommended radiative/convective splits for internal heat gains and is copied below in Figure B1. We estimate that 46% of solar energy and 54% of convection/conduction contributes to the total exterior surfaces energy. For a SHCG > 0.5, we assume that 33% of solar energy and 67% of convection/conduction contributes to the total window energy. We understand that there are better methods to calculate convection and radiation impinging on external surfaces. This method was used to avoid analysis that can be eventually output by the EnergyPlus model.

Table 14 Recommended Radiative/Convective Splits for Internal Heat Gains

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction	Comments
Occupants, typical office conditions	0.6	0.4	See Table 1 for other conditions.
Equipment	0.1 to 0.8	0.9 to 0.2	See Tables 6 to 12 for details of equipment heat gain and recommended radiative/convective splits for motors, cooking appliances, laboratory equipment, medical equipment, office equipment, etc. Varies; see Table 3.
Office, with fan	0.10	0.9	
Without fan	0.3	0.7	
Lighting			
Conduction heat gain			
Through walls and floors	0.46	0.54	
Through roof	0.60	0.40	
Through windows	0.33 (SHGC > 0.5) 0.46 (SHGC < 0.5)	0.67 (SHGC > 0.5) 0.54 (SHGC < 0.5)	
Solar heat gain through fenestration			
Without interior shading	1.0	0.0	Varies; see Tables 13A to 13G in Chapter 15.
With interior shading			
Infiltration	0.0	1.0	

Figure B1 (continued) (2009)

**Figure B1** Recommended Radiative/Convective Splits for Internal Heat Gains in Nonresidential Areas. Copied from ASHRAE Handbook- Fundamentals (2009) ch. 18, table 14.

Convection is also assumed to be the main conveyor of heat through infiltration, and as air supply to the AHU. Air flow supplied to the AHU & mechanical ventilation is assumed to be proportional to a 10% fraction of outside air supply.

#### Windows to Interior Lighting:

The EnergyPlus model does not account for daylighting, or the use of natural light. Published solar radiation data for Philadelphia (Table A12) are used to estimate average transmitted solar radiation for an unshaded single-strength clear double glazing window with glass thickness 0.125 in.

The transmitted solar radiation enters a living space, and accounts for radiation and absorption. The EnergyPlus shading summary report outputs yearly average sunlit fraction across simulated windows, which corresponds to how much of the windows are sunlit. Annually, the average sunlit fraction is ~0.384. The assumed energy flow for windows to interior lighting is:

Windows → Interior Lighting =

#### Fenestration Heat Gain:

The total fenestration heat gain depends on radiation exchange, conductive and convective heat gains. A simplified calculation of energy flow through fenestration, assuming all radiating surfaces are the same as the exterior air temperature, is:

Where:  $U$  = U-factor, Btu/hr-ft<sup>2</sup>-°F  
 $T_{in}$  = room temperature, °F  
 $T_{out}$  = average exterior air temperature, °F  
 $A_{pf}$  = total projected area of fenestration (glass), ft<sup>2</sup>  
 $SHGC$  = Overall solar heat gain coefficient, non-dimensional  
 $E_t$  = incident total irradiance, Btu/hr-ft<sup>2</sup>

[2009 ASHRAE Fundamentals 18.15]

AHU & Mechanical Ventilation:

B101 has three AHUs that supply cooling/heating/ventilation to different sections of the building. The AHUs draw in fresh air, and use heating and cooling coils. A supply fan helps cycle air from outside, through the AHU, and into the various zones through a VAV terminal. The VAV terminals have a reheat coil and dampers to control zone temperature. Three exhaust fans not tied to the HVAC system blows air out of the attic to balance the building. As described in Table A9, ~ 47% of the total fresh air intake is exhausted from the building after conditioning. Based on sensor data from EEBHub, the majority of the remaining fresh air intake is likely exiting the building shell via exfiltration. The flow of the AHU split to the thermal environment and exhaust is representative of this air flows percentage.

Water Heater (WH):

The assumptions for the water heater energy use flows are below where  $E_{WH}$  is the water heater energy usage,  $EF$  is the Energy Factor, and  $RE$  is the Recovery Efficiency.

1.  $WH \rightarrow \text{Warm Water} = \text{Warm Water} \rightarrow \text{drain/sewer} = (EF)E_{WH}$
2.  $WH \rightarrow \text{Exhaust} = (1 - RE)E_{WH}$
3.  $WH \rightarrow \text{building thermal envelope}$   
 $= E_{WH} - [WH \rightarrow \text{Exhaust}] - [WH \rightarrow \text{Warm Water}]$   
 $= E_{WH} - [(1 - RE)E_{WH}] - [(EF)E_{WH}]$

For October 2012, of the NG consumed by the two DWHs, ~ 37.6% went into creating hot water, 31% was lost to the building via the recirculation loop, and the remaining 31.4% was lost as standby and flue loss.

DHW Pumps:

The domestic hot water pumps are assumed to convert their energy to the building thermal envelope building. A DHW recirculation pump is currently broken, has a heat loss possibly from a thermal siphon effect, and is assumed that most of this heat is lost to the building. [email: S.Wagner].

Boiler:

The boiler is used only part of the year, turned off in the summer time. 83% of the natural gas is converted into usable BTUs (design efficiency)

Interior Equipment:

Interior Equipment is assumed to convert their energy to the building thermal envelope. While many loads in EEBHub are monitored, the data is used to calibrate the EnergyPlus model. This includes appliances, loads plugged into receptacles, and small fraction of lighting

Exterior Lighting:

Exterior lighting is assumed not to contribute to the building thermal envelope.

## Appendix C: Acronyms and Definitions

### Acronyms

AHU	Air Handling Unit
B101	Building 101
EER	Energy Efficiency Ratio
EF	Energy Factor
IEER	Integrated Energy Efficiency Ratio
NG	Natural Gas
RE	Recovery Efficiency
SEER	Seasonal Energy Efficiency Ratio
SHGC	Sensible Heat Gain Coefficient
VT	Visible Transmittance

### Definitions

**Nominal Thermal Efficiency:** This required numeric field contains the heating efficiency (as a fraction between 0 and 1) of the boiler's burner. This is the efficiency relative to the higher heating value (HHV) of fuel at a part load ratio of 1.0 and the temperature entered for the Design Boiler Water Outlet Temp. Manufacturers typically specify the efficiency of a boiler using the higher heating value of the fuel. For the rare occurrences when a manufacturers (or particular data set) thermal efficiency is based on the lower heating value (LHV) of the fuel, multiply the thermal efficiency by the lower-to-higher heating value ratio. For example, assume a fuel's lower and higher heating values are approximately 45,450 and 50,000 kJ/kg, respectively. For a manufacturers thermal efficiency rating of 0.90 (based on the LHV), the nominal thermal efficiency entered here is 0.82 (i.e. 0.9 multiplied by 45,450/50,000).

**Seasonal Energy Efficiency Ratio (SEER):** The SEER rating of a unit is the cooling output during a typical cooling-season divided by the total electric energy input during the same period. The higher the unit's SEER rating the more energy efficient it is. In the United States, SEER is computed by measuring cooling in British thermal unit (BTU) and energy consumed in watt-hours, so the resulting number is measured in units of 0.29307107. Thus, a US SEER of 14 BTU/W-h corresponds to an efficiency ratio of only 4.1. The rest of this article talks about SEER in the United States.

**Energy Efficiency Ratio (EER):** EER is a measure of efficiency in the cooling mode that represents the ratio of total cooling capacity (Btu/hour) to electrical energy input (Watts). of a particular cooling device is the ratio of *output* cooling (in Btu/hr) to *input* electrical power (in watts) at a given operating point. EER is generally calculated using a 95F outside temp and an inside (actually return air) temp of 80F and 50% relative humidity; Usually used as the full-load or peak rating

**Integrated Energy Efficiency Ratio (IEER):** IEER is a weighted average of the unit's efficiency at four load points –100%, 75%, 50% and 25% of full cooling capacity

$$\text{IEER} = (0.020 * A) + (0.617 * B) + (0.238 * C) + (0.125 * D)$$

Where:

A = EER at 100% net capacity at AHRI standard rating conditions

B = EER at 75% net capacity and reduced ambient (81.5°F for air-cooled)

C = EER at 50% net capacity and reduced ambient (68°F for air-cooled)

D = EER at 25% net capacity and reduced ambient (65°F for air-cooled)

[[http://www.cee1.org/cee/mtg/06-10mtg/files/ComHVAC\\_ICF\\_Odell.pdf](http://www.cee1.org/cee/mtg/06-10mtg/files/ComHVAC_ICF_Odell.pdf)]

**Infiltration:** The inadvertent flow of air into a building through breaks in the exterior surfaces of the building. It can occur through joints and cracks around window and skylight frames, sash, and glazings.

**Solar heat gain coefficient (SHGC):** The fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. The Solar Heat Gain Coefficient has replaced the Shading Coefficient as the standard indicator of a window's shading ability. It is expressed as a number without units between 0 and 1. A window with a lower Solar Heat Gain Coefficient transmits less solar heat, and provides better shading.

[<http://windows.lbl.gov/pub/selectingwindows/window.pdf>]

**U-Factor (U-Value):** A measure of the rate of heat flow through a material or assembly. It is expressed in units of Btu/hr-ft<sup>2</sup>-°F or W/m<sup>2</sup>-°C. Window manufacturers and engineers commonly use the U-factor to describe the rate of non-solar heat loss or gain through a window or skylight. Lower window U-factors have greater resistance to heat flow and better insulating value.

**Visible Transmittance:** The percentage or fraction of visible light transmitted by a window or skylight.

## Appendix D: EnergyPlus Output Table Descriptions

Program Version:EnergyPlus-64-MP 7.1.0.012, 10/9/2012 8:43 PM (Simulation Timestamp: 2012-10-09 20:54:29)

Tabular Output Report in Format: HTML

Building: Building

Environment: PHL\_AP\_AMY

### **Report: Annual Building Utility Performance Summary**

*For: Entire Facility*

*Values gathered over 8760.00 hours*

The Annual Building Utility Performance Summary report provides an overview of energy consumption in the building for different end uses.

Site and Source Energy (including per bldg. area, per conditioned bldg. area)

- Indicates the total site and source energy use. For electricity the net electricity from the utility is used for the electric contribution.

Site to Source Energy Conversion Factors

- The site to source conversion factors are based on those entered by the user. These are entered in the EnvironmentalImpactFactors object and FuelFactors objects

Building Area

- Shows the total floorspace of the building and the conditioned floorspace.

End Uses - The values in the *End Uses* sub-table are from report meters. To determine which components are attached to each end-use meter, consult the meter details output file (\*.mtd).

- Not all fuels have corresponding end uses
- The source of the resource does not affect this table
- Other Fuel column includes fuel oil#1, fuel oil#2, gasoline, coal, propane and diesel.
- The district heating column also includes steam

End Uses by Subcategory (i.e. cooling, interior lighting by area, exterior lighting, interior equipment by area, fans, pumps, water systems)

Utility Use Per Conditioned & Total Floor Area (lighting, HVAC, other)

- HVAC includes fans, pumps, heating, cooling, heat rejection, humidification, and domestic hot water heating.
- The Other Fuel column includes fuel oil#1, fuel oil#2, gasoline, coal, propane and diesel.
- The district heating column also includes steam.

Comfort and Setpoint Not Met Summary

In the *Comfort and Setpoint Not Met Summary* sub-table, facility hours represents the total number of hours that any single zone did not meet the comfort or setpoint criteria. It is not weighted by number of zones or number of occupants

### **Report: Input Verification and Results Summary**

*For: Entire Facility*

The Input Verification and Results Summary report provides a summary of some of the most common input assumptions that are not included in any of the other predefined reports.

ENVELOPE: Window-Wall Ratio (conditioned and all), Skylight-Roof Ratio

PERFORMANCE: Zone Summary; includes internal load summary for each zone (area, conditioning use, volume, gross wall area, window glass area, lighting, people, plug and process)

### **Report: Demand End Use Components Summary**

*For: Entire Facility*

The Demand End Use Components Summary report shows the demand breakdown by component end use at the time that the peak demand for each source of energy is set. The time of the peak demand is shown in the first row. The contributions of each end use at the time of the peak demand of the energy source is shown in this report.

End Uses

## End Uses By Subcategory

### **Report: Source Energy End Use Components Summary**

For: Entire Facility

Values gathered over 8760.00 hours

The Source Energy End Use Components Summary report produces a report that includes three tables. These tables display source energy by fuel type that is calculated based on site to source energy factors specified by the user in the EnvironmentalImpactFactors and FuelFactors objects. The last two tables display the source energy in terms of area normalized metrics.

### **Report: Climatic Data Summary**

For: Entire Facility

The Climatic Data Summary provides some statistics from the .STAT file concerning the selected weather. The Stat file must be available (it is included with all the weather files on the EnergyPlus website) for the report to be fully produced.

### **Report: Envelope Summary**

For: Entire Facility

Opaque Exterior, Interior Fenestration, Exterior Door

The Envelope Summary report provides a summary of the elements of the envelope of the building. The first table describes the exterior opaque elements and the second table describes the fenestration elements. Reflectance is defined as one minus the thermal absorptance.

Interior Fenestration includes all non-opaque surfaces

### **Report: Shading Summary**

For: Entire Facility

The Shading Summary report shows how much of each window is sunlit at different times of the year and also includes a summary of the window controls.

Sunlit Fraction

- the fraction of the window that is sunlit for nine specific times of the year, These nine times were chosen to represent the range of sun angles

Window Control

### **Report: Lighting Summary**

For: Entire Facility

Interior Lighting, Exterior Lighting

The Lighting Summary report provides a description of the interior and exterior lighting systems being simulated. It also provides a summary of daylighting controls. The Interior Lighting table has three columns that are explained below:

Scheduled Hours/Week [hr] - In the schedule shown, this represents the average weekly sum of hourly values. It is based on a full year even if the simulation is only performed for part of the year. It is not affected by daylighting.

Hours/Week > 1% [hr] – This represents the average hours per week that are above 1% of the design value.

Full Load Hours/Week [hr] – This is based on consumption and hours that the consumption occurred. It is dependent on the run period used. When simulating only a portion of the year, the value depends on which days of the year (the number of weekdays versus weekend days, for example) are simulated. It also indicates the impact of daylighting control.

### **Report: Equipment Summary**

For: Entire Facility

Central Plant, Cooling Coils, DX Cooling Coils, DX Heating Coils, Heating Coils, Fans, Pumps, Service Water Heating,

The Equipment Summary report provides a summary of the HVAC related equipment in the building. The central chiller example shows the most common type of chillers, boilers and towers used in EnergyPlus. The remaining subtables cover DX coils, fans and water heating equipment. Not every type of HVAC equipment is represented in this report.

Cooling Coils

- These values are calculated by calling the cooling coil simulation routine with the rated inlet conditions: inlet air dry bulb temperature = 26.67C, inlet air wet bulb temperature = 19.44C, inlet chilled water temperature = 6.67C.

DX Cooling Coils

- summarizes the Standard Rating (Net) Cooling Capacity, SEER, EER and IEER values at AHRI standard test. Currently, these values are only reported for coil type = Coil:Cooling:DX:SingleSpeed with condenser type = AirCooled.

Heating Coils

- The capacity is calculated by calling the heating coil simulation routine at the rated inlet conditions: inlet air dry bulb temperature = 16.6C, inlet relative humidity = 50%, inlet hot water temperature = 82.2C.

**Report: HVAC Sizing Summary**

For: Entire Facility

Zone Cooling, Zone Heating, System Design Air Flow Rates

The HVAC Sizing Summary report provides information on the zone cooling and heating sizing and the peak load conditions as well as information about the system air flow sizing.

Note: values listed as "calculated" are the unaltered result of the zone or system sizing calculations, using the design sizing period weather and schedules specified in the input. Values listed as "user specified" are either the calculated values modified by global or zone sizing factors or values specified with the flow/zone or flow/system design air flow method

**Report: System Summary**

For: Entire Facility

Time Not Comfortable Based on Simple ASHRAE 55-2004, Time Setpoint Not Met

The System Summary report provides information about some of the primary components in the system including the economizer and demand controlled ventilation. In addition, this report describes when the zone conditions are not comfortable or when set points are not met.

In the *Time Not Comfortable Based on Simple ASHRAE 55-2004* and Time Setpoint Not Met sub-tables, The reported time represents the total number of hours that a given zone did not meet the comfort or setpoint criteria. For the Facility row, this is the total numbers of hours that one or more zones were out of range. The values are not weighted by number of zones or number of occupants.

**Report: Outdoor Air Summary**

For: Entire Facility

Average Outdoor Air During Occupied Hours, Minimum Outdoor Air During Occupied Hours,

The Outdoor Air Summary provides information for each zone on the average and minimum ventilation provided.

The reports described so far in this section are displayed when specified in the Output:Table:Predefined object. They are either on or off and are not customizable. The next few types of tabular reports are customizable. You can specify the report variables being used in each one.

**Report: Object Count Summary**

For: Entire Facility

This report provides the count on the number of specific objects in the file.

Surfaces by Class, HVAC, Input Fields

**Report: Energy Meters**

For: Entire Facility

This report provides the details on all the energy meters generated by the simulation.

The Energy Meters Summary (which is a slight misnomer as some meters may not be strictly energy) provides the annual period (runperiod) results for each meter (reference the meter data dictionary file (.mdd) and/or the meter details file (.mtd). The results are broken out by fuel type (resource type) in this report

Annual and Peak Values – Electricity, Annual and Peak Values – Gas, Annual and Peak Values – Water, Annual and Peak Values – Other

Facility meters contain all the energy of a fuel type.

Building meters contain the sum of each zone's energy.

Plant meters contain the energy from the plant equipments.

**Report: Sensible Heat Gain Summary**

For: Entire Facility

Annual Building Sensible Heat Gain Components, Peak Cooling Sensible Heat Gain Components, Peak Heating Sensible Heat Gain Components,

This report is more fully described in the Input Output Reference but represents the major heat gain components for each zone as well as the HVAC loads satisfied.

- The balance is shown as "Opaque Surface Conduction and Other Heat Addition" and "Opaque Surface Conduction and Other Heat Removal" which is a term indicating the effect of the walls, floors and ceilings/roof to the zone as well as the impact of the delay between heat gains/losses and loads on the HVAC equipment serving the zone.

***Report: Component Sizing Summary***

The Component Sizing Summary report includes details on many of the HVAC components in the simulation. For each of the components, one or more parameters are shown.

AirTerminal:SingleDuct:VAV:Reheat, ZoneHVAC:PackagedTerminalHeatPump, Coil:Cooling:DX:SingleSpeed,  
Coil:Heating:DX:SingleSpeed, Fan:OnOff, Coil:Heating:Electric, ZoneHVAC:Baseboard:Convective:Water, Branch,  
Controller:WaterCoil, Coil:Cooling:DX:TwoStageWithHumidityControlMode, PlantLoop, Boiler:HotWater, WaterHeater:Mixed,

***Report: Surface Shadowing Summary***

For: Entire Facility

Surfaces (Walls, Roofs, etc.) that may be Shadowed by Other Surfaces

The Surface Shadowing Summary report summarizes how the surfaces may cast shadows on other surfaces.

## Appendix E: Basic Diagram of B101 HVAC System

